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UNITED STATES
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BUREAU OF MINES
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INFORMATION CIRCULAR

LITHIUM

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BY

FRANK L. HESS

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

LITHIUM[1]

By Frank L. Hess[2]

In the first part of that little space of time that we have designated as the nineteenth century, chemistry had reached a wonderful stride.

Viewed from the present heights attained by the efforts of innumerable chemists with perfected apparatus, pure reagents, air under pressure, water, gas, and electricity conducted to the desk, and numberless other helps, it seems marvelous that chemists of that day obtained such results.

In 1820, about half of the elements had been discovered; of these discoveries, Swedes had made 15 or more, about one-third of the elements then known and nearly half of those discovered after 1700.

The Swedes were great metal miners and metal workers, and their metals were found in rocks that had been disturbed and worked over and over by the restless earth, so that with their iron and copper and with their granite were great quantities of minerals that attracted such trained prospectors and constantly challenged investigation, with the result that they discovered the heavy metals cobalt, nickel, manganese, tungsten, molybdenum, and tantalum, and also selenium, barium, and calcium, which accompanied their metallic ores. In one of the merely attractive minerals, yttrium was discovered, and yet to this day the determination of tantalum and yttrium tests the skill of chemists.

In 1817, J. A. Arfvedson, a well-to-do young man 25 years old, analyzed petalite, a mineral found in pegmatite at the iron mine on the island of Uto, 25 miles southeast of Stockholm, and obtained from it a salt of a new alkali metal. It differed from potassium in that it was not precipitated by tartaric acid and from sodium in that its carbonate is not readily soluble. He named it lithium to signify that it came from a rock, as the two previously known alkali metals, sodium and potassium, were said to have been found in vegetal products. His account of the discovery was not published until 1819.

1/ The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Information Circular 7054."
A lecture delivered October 25, 1938, as one in the annual series given by members of the Bureau of Mines under the auspices of the University of Maryland.

2/ Principal mineralogist, Bureau of Mines, College Park, Md.

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Spodumene and lepidolite occurred in the pegmatite from which the petalite came, and Arfvedson showed that they too contained lithium. He also studied the principal lithium salts; but, oddly enough, although the blowpipe was expertly used by mineralogists of the day, he did not discover the beautiful flame test.

Ten years before this time, Davy had isolated potassium, sodium, barium, strontium, calcium, and magnesium by electric reduction of the chlorides, obtaining his current from a bank of batteries.

Arfvedson tried to reduce lithium similarly but did not have a sufficient number of batteries. Soon after, both Brandes and Davy, having more powerful groups of batteries, isolated the metal.

In 1855, Bunsen and Mattheisen succeeded in preparing enough of the metal for a thorough study. They placed pure lithium chloride in a small thick-walled porcelain crucible, heated by an alcohol lamp, and passed through the chloride a current from 4 to 6 Bunsen cells, the carbon-zinc batteries. A globule of white metal the size of a pea formed within 2 or 3 minutes. This they removed with an iron spoon and placed in mineral oil and repeated the operation every 3 minutes until they had reduced an ounce of chloride. In their study they showed that lithium is widely spread in minerals, plants, and animal tissues.3/

As found by these and other workers, lithium is a silvery-white metal and is the most resistant of the alkali metals to atmospheric attack; but it readily decomposes water, though it does not take fire spontaneously, and, unless carefully protected from humid air, it is soon covered by a white coating of lithium hydroxide. It has the lowest atomic weight of the solid elements, 6.94. Only hydrogen and helium have lighter atomic weights.

Its specific gravity is likewise the lowest for the solid elements, 0.543 at 20° C. (68° F.), and a cubic foot would weigh only 33.9 pounds, which may be compared with 169 pounds for aluminum and 710 pounds for lead. The hardness of lithium on the Mohs scale is said to be 0.6, which means that it is easily scratched by talc. It is softer than lead and harder than sodium. It is very malleable and ductile and can be rolled into thin plates or drawn into wire. It melts at 180° C. (356° F.) and boils at 1,400° C. (2,550° F.).

Lithium has three isotopes having atomic weights of 6.0167, 7.0180, and 8.0190 respectively, of which the third is radioactive.

3/ Much of the preceding data has been taken from Mary E. Weeks' The Discovery of the Elements, 1933, pp. 125-126, and others, and from Mellor's A Comprehensive Treatise on Inorganic Chemistry.

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DISTRIBUTION IN NATURE

Only 17 or 18 lithium minerals are known and all but one are thought to be found only in pegmatites. By a lithium mineral I mean a mineral of which lithium is an essential part. Below the following list of lithium minerals are three other minerals that carry lithium under certain conditions.

Lithium Minerals

		Percent Li
Amblygonite	$Al_2O_3.2LiF.P_2O_5.Li_2O$	4.24-5.26
Cryolithionite	$3LiF.3NaF.2AlF_3$	5.35
Holmquistite	Lithium glaucophane	1.14
Lithiophilite	$Li_2O.2MnO.P_2O_5$	4.61-5.00
Manandonite	$7Al_2O_3.2Li_2O.2B_2O_3.6SiO_2$	2.13
Mica:		
Cookeite	Uncertain	1.51
Hallerite	do.	.61
Irvingite	do.	2.38
Lepidolite	do.	2.16-3.15
Polylithionite	do.	4.85
Zinnwaldite	do.	1.76-2.67
Petalite	$Li_2O.Al_2O_3.8SiO_2$	1.40-2.26
Sicklerite	$Fe_2O_3.6MnO.4P_2O_5.3(Li,H)_2O$	2.04
Snarumite	Al silicate?	1.15
Spodumene	$Li_2O.Al_2O_3.4SiO_2$	2.40-4.08
Triphylite	$Li_2O.2(Fe,>Mn)O.P_2O_5$	4.36-5.02
Bityite	Uncertain Ca,Al silicate	1.46
Beryls, colored		tr. - 0.78
Tourmalines, colored		tr. - 0.84
Biotite		0. - 1.20

All colorless and colored tourmalines - red, pink, bright and dark green, and blue - are said to carry lithium, as do the colored beryls, yet lithium colors nothing. Where pegmatites cut biotite schists or gneisses, the biotite is sometimes enlarged considerably by the pegmatite solutions; all such biotites so far tested carry lithium, and some carry rubidium and cesium. Besides those minerals listed, lithium has been found as a trace or more in many others. Dieulafait gave a list of 140 minerals said to contain more or less lithium.

Named in order of their lithium content, the principal minerals are amblygonite, spodumene, lepidolite, and zinnwaldite. I have not included here cryolithionite, lithiophilite, or triphylite because they have not

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been found in commercial quantity. All but zinnwaldite are found only in pegmatites or veins closely related to pegmatites, but zinnwaldite has been found in some quantity with the tin veins of Saxony and in less quantity with other high-temperature deposits in other countries.

By pegmatites I mean those coarse, uneven-grained rocks having the form of dikes or veins found in the top of or in the rocks lying over or around granite intrusions. The lithium minerals have invariably been introduced by very hot solutions that flowed through the pegmatites after they had been crystallized and at least somewhat cooled.

Pegmatites are common almost everywhere that erosion has exposed the light-colored granitic rocks, but comparatively few carry lithium minerals and still fewer carry the minerals in any considerable quantity.

But before going on with the pegmatites, some of the other occurrences of lithium must be noticed. I have said that the lithium minerals have been introduced into the pegmatites by hot solutions, and these solutions may not have been water but steam. It is, therefore, what might be expected, to find that some hot springs carry lithium. The quantity of lithium in solution is small, but probably the solutions that formed the minerals in the pegmatites were also very dilute. Probably, also, most of the springs that have been advertised as "lithia springs" have carried too little lithia to cast a shadow on an analysis. However, when in 1860 Bunsen and Kirchoff[4] evaporated 44,200 kilos (48.7 short tons) of hot spring water at Durkheim, Germany, they obtained 39.1 mg. of lithium chloride, 0.21 mg of rubidium chloride, and 0.17 mg of cesium chloride per liter of water. This would indicate that in the 49 tons evaporated, there were about 1,728 grams of lithium chloride, 9.2 grams of rubidium chloride, and 7.3 grams of cesium chloride.

Where such spring waters have flowed into some basin from which the water evaporated, the lithium, like sodium and other salts, has been left behind. Brine below the salt in Great Salt Lake Basin carries 4 mg Li_2O per liter, just about one-tenth as much as the water of the Durkheim Spring, and the brine of Searles Lake in the Mohave Desert of California carries 0.032 percent[5] LiCl. Supposing this brine to have a specific gravity of 1.2, it would carry 372 mg per liter, almost 10 times as much as the Durkheim Spring and a hundred times as much as the brine of Salt Lake. I will refer to Searles Lake again.

Undoubtedly many lakes without outlets carry lithium in their brines, and so must the great salt beds. In the Muddy Mountains of southwestern Nevada, an impure magnesite that was probably formed in some such basin

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4/ Kirchoff, G., and Bunsen, R., Chemical Analysis by Spectrum Observations: 2d Mem., Phil. Mag., 4th ser., vol. 22, November 1861, pp. 329-349; Trans. from Poggendorff's Ann., no. 7, 1861.

5/ Teeple, John E. The Industrial Development of Searles Lake Brines. Am. Chem. Soc. Mon. 49, 1929, p. 18.

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carries from 0.17 to as much as 1.77 percent Li_2O. At Hector, Calif., a clay in an old playa carries 0.60 to 1.12 percent Li_2O 6/; clay 16 miles northeast of Amboy, Calif., 0.50 percent Li_2O, and material from another old playa in northern Arizona has a comparable lithia content. There are probably numerous other such sediments in the playas of the West that have received drainage from lithium-bearing hot springs. The flow from the lithium-bearing hot springs and rocks finally reaches the ocean, the water of which has been shown to carry a trace of the metal.

Not let us go back to the pegmatites.

Lepidolite is the most widely spread of the lithium minerals. In Africa it is found in considerable quantity in Northern Rhodesia, and in much larger quantity in South-West Africa, the former German colony over which the Union of South Africa has a mandate. In South-West Africa the quantity available seems to be large, and with it is amblygonite, which is being exploited. Lepidolite and other lithium minerals have been found in comparatively small quantity in Madagascar.

In Asia, Dr. D. J. Mushketof, formerly head of the U. S. S. R. Geological Survey, told me that there were large deposits of lepidolite near Samarkand. No details are known to have been published. Some lepidolite is reported from central India, and small quantities of lithium minerals have been found in China and Japan.

In Europe, Portugal has been producing some hundreds of tons of lepidolite annually, but so far as is known it has no other lithium minerals.

Spain has produced some amblygonite from veins closely related to pegmatites; France has produced some amblygonite and some montebrasite, a variety of amblygonite in which part of the fluorine is replaced by hydroxyl.

In Australia some amblygonite has been produced from the alternately scorched and parboiled Northern Territory and some amblygonite and other lithium minerals from Western Australia.

Germany has produced zinnwaldite and many hundred tons of low-grade lepidolite. Sweden, where lithium was discovered, has newly-found deposits of amblygonite 6A/, lepidolite, petalite, and spodumene, and has produced some hundreds of tons of amblygonite.

On the Western Continent, deposits of large crystals of spodumene are reported from northwestern Argentina, and very large deposits of lepidolite are rumored to exist in Brazil. Although no details are at hand, it would not be surprising to learn that there were such deposits in some of the numerous pegmatites of that country.

6/ Foshag, W. F. and Woodford, A. O. Bentonitic Magnesian Clay-mineral from California. Am. Min. vol. 21, 1936, p. 241.

6A/ Quensel, Percy. Minerals of the Varutrask pegmatite. VIII. The Amblygonite Group. Geol. Fören. I Stockholm Förhandlingar. Vol. 59, Nov.-Dec. 1937, pp. 455-468.

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In North America there are large deposits of lepidolite at Pointe du Bois, Manitoba, and near Pala, Calif., with smaller deposits near Ohio City, Colo, and Keystone, S. Dak., and still smaller ones at other places. The Manitoba deposits also contain spodumene, amblygonite, and montebrasite. Amblygonite has been found in some very large masses, one reaching possibly a thousand tons, in the Black Hills of South Dakota. The amblygonite is high in lithium and easy to reduce and so sells first, but far beyond the amblygonite deposits in their total lithium content are great deposits of spodumene in the Black Hills and North Carolina. These spodumene deposits are so unique that I hope you will find interest in a short description of them.

The first spodumene found in this country was in glacial boulders in Massachusetts, and not for many years was the origin, a mile or two away, known. Other deposits were found in New England, but they were not very striking.

After gold was discovered in the Black Hills of South Dakota, the country swarmed with prospectors, and about 1880 the Etta pegmatite, 1 1/2 miles south of Keystone, was located and worked for mica. Then tin was found in it and in other pegmatites and one of the great American mining fiascos followed, with the loss of millions of dollars to British and American investors. Meanwhile, it was found that the pegmatite was a marvelous treasure-house of rare minerals. Before this time, 2-foot crystals of spodumene found in New England had been described as "enormous." Here they were found many feet long, and from a tin mine the Etta was changed to a lithium mine, and so it has remained to this day.

The pegmatite occupies the center of a knob which stood about 300 feet above a creek at its base. A horizontal cross section of the pegmatite is shaped about like that of a human skull and is about 300 feet long by 250 feet wide. A great quantity of mixed minerals has been mined from its top, but the mass is now almost entirely quartz through which huge crystals of spodumene are mixed at every possible angle like toothpicks in a translucent gel. In 1904, a crystal 42 feet long and 3 feet by 6 feet in cross section was found, and the adjective "enormous" applied to the New England crystals must be transferred. The crystal weighed about 65 tons, but decay had attacked the spodumene of the upper part of the deposit, so that this giant yielded only 37 tons of good spodumene - a pretty fair carload!

Decay makes the excellent cleavage of spodumene so prominent that the big crystals look like wood, and the miners always refer to them as "logs." The last time I visited the mine, the crystals in sight were only 8 or 10 feet long and a foot or so thick. (See fig. 1).

On two other claims in the Black Hills are also huge crystals. In workings on Tin Mountain, 7 miles northwest of Custer, a crystal,

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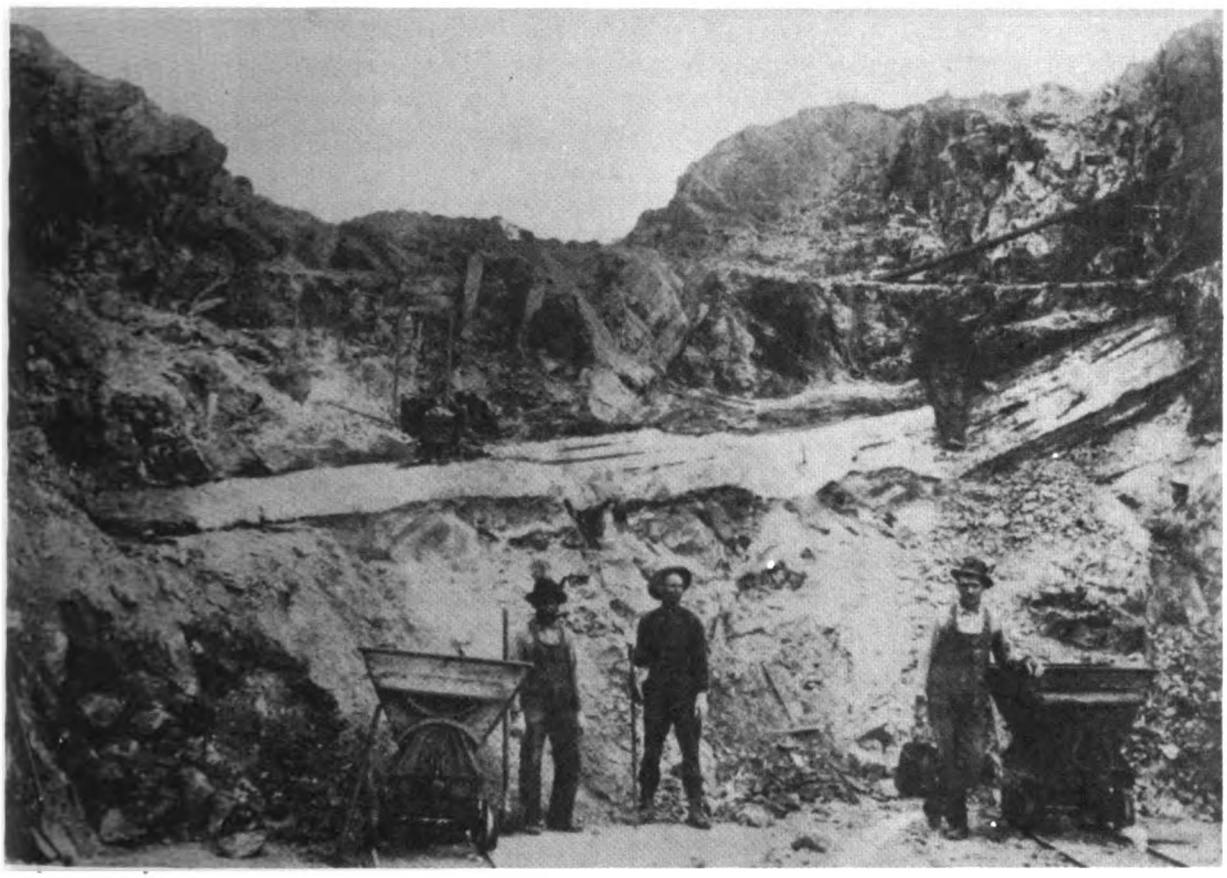

Figure 1.- Spodumene crystal 42 feet long and 3 by 6 feet in cross section found in Etta mine, Keystone, S. Dak.

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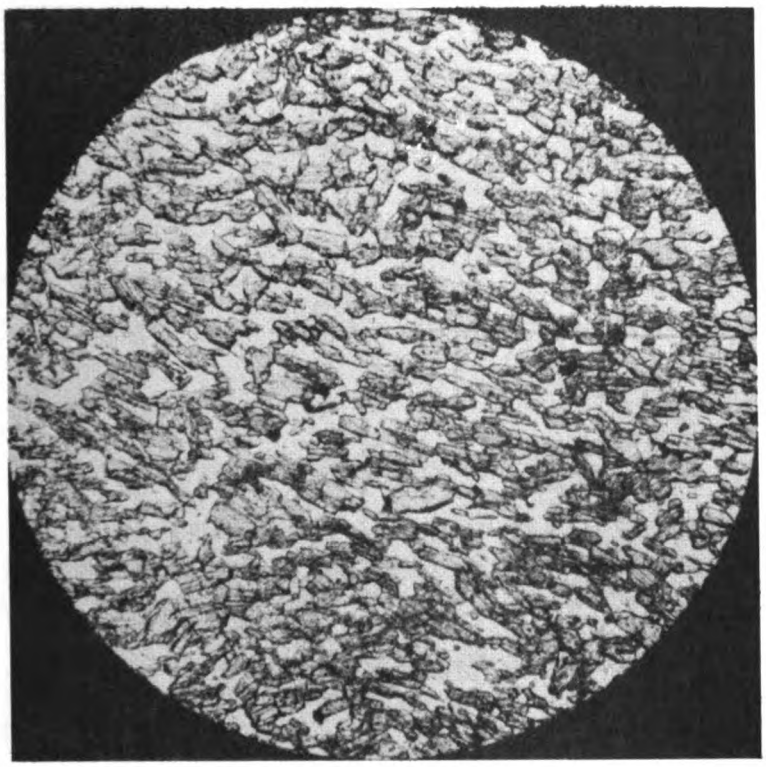

Figure 2.- Spodumene-quartz mixture, Tantalum Hill, Tinton, S. Dak. X30.

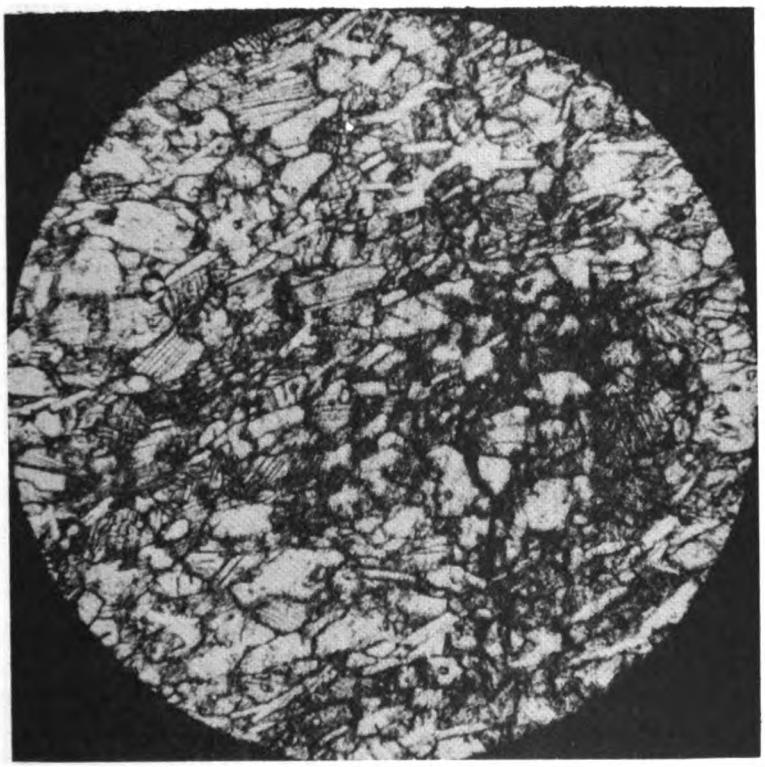

Figure 3.- Almost pure spodumene from Tantalum Hill, Tinton, S. Dak. X30.

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largely mined out when I saw it, was 36 feet long and had a double-crescent cross section 1 foot by 3 feet. It has been estimated that some crystals on the Beecher claim 5 miles south of Custer weigh 15 to 20 tons each.7/

There are many other deposits in the Hills that contain less spectacular crystals but carry large quantities of lithium.

At Tinton, about 60 miles northwest of the Etta mine, is a deposit that is remarkable because a large part of its crystals are as notably small as the Etta's are big. There is at that place a large pegmatite about 880 feet long and 400 feet wide, with a horizontal cross section somewhat like that of an enlongated potato with a bite out of the northeast edge.

This pegmatite and many others of the locality carried some tin, and numerous mining engineers and geologists, of whom I was one, examined them.

A rather prominent fine-grained white rock on this particular claim had shiny little enlongated cleavage faces in the mass and apparently all of us thought it to be a mixture of albite and quartz such as was found on other claims. Then about 3 years ago some of the same material was sent to me for a formal determination and it was necessary to give it a real examination. When a section was made for the microscope, I found that the entire mass was a half-and-half mixture of quartz and minute crystals of spodumene. (Fig. 2.) The crystals of spodumene are less than a millimeter long and only a fourth or a third as thick. Some other specimens have been almost pure spodumene (Fig. 3), and there is probably more than 100,000 tons of spodumene-bearing rock in the deposit, though not all as rich as the sections shown in the illustrations.

Just after this surprising development, a friend sent me some spodumene from Kings Mountain, N. C., and at various times I have visited the locality with members of the staff of the United States National Museum and of the Bureau of Mines and found there fully as surprising a situation.

In 1881, a transparent green spodumene in small crystals from Alexander County, 40 miles north of Kings Mountain, was described and named hiddenite.8/ A few gems cut from it sold for high prices, but probably a total of only a few small handfuls of crystals have been found. In the neighborhood of Kings Mountain, as in the Black Hills, tin had been found in pegmatites, and a lot of money had been spent in futile mining. Twenty-five years after the hiddenite was found, Graton, of the U. S. Geological Survey, because of the lack of market, noted without

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7/ George S. Bland. Private report.

8/ Smith, J. L., Hiddenite, an Emerald Green Variety of Spodumene: Am. Jour. Sci., 3rd ser., vol. 21, 1881, pp. 128-130.

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much emphasis in a report that spodumene was present in the tin-bearing pegmatites. After another 25 years, in 1931, Keith and Sterrett in much the same way and for the same reason noted the spodumene in a Survey folio.9/ Geologic literature is now served in such quantity that no one can digest it all, and unless such items are emphasized in some way they usually are lost.

A description of the deposits, in the Engineering and Mining Journal10/ in 1935 brought a number of serious investors into the field.

The spodumene-bearing pegmatites have been found from Grover, on the South Carolina line, to Lincolnton, about 25 miles northeast. The individual bodies range in width from 6 to possibly 200 feet and reach possibly half a mile in length. The crystals are neither very large (fig. 4) nor is there a great quantity of very small ones, but in general the pegmatites carry probably 15 percent or more of spodumene averaging perhaps the size of one's finger, and its distribution is remarkably even.

The spodumene from North Carolina, like nearly all spodumene from whatever place, carries a fractional percentage of iron, too large for many uses. Here and there a spodumene carries less iron, but about 0.5 percent seems to be the general content.11/

It seems safe to estimate that, if pieced together, the pegmatites would be more than equivalent to a single pegmatite 10 feet wide extending the whole length of the belt, about 25 miles. Supposing a depth of 100 feet and a content of 15 percent of spodumene carrying 6.50 percent of lithia, there would be available about 1,650,000 tons of spodumene containing 50,000 tons of elemental lithium, undoubtedly the largest known group of deposits in this or any other country.

When one contemplates the quantity of hot water that must have flowed through cracks in the pegmatites to bring in such a great quantity of this light metal, imagination bogs down, especially when one considers the origin of the water. It may be well to enlarge on this point briefly.

All lithium-bearing pegmatites have originated from molten granite, but molten granite is not merely the rock we see on the surface of the earth heated until it becomes fluid; it is a liquid composed of water and the substances which, on cooling, crystallize out to make the rock we see. As the minerals crystallize, the water is set free probably at

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9/ Keith, Arthur, and Sterrett, Douglas B. Gaffney-Kings Mountain Folio, South Carolina-North Carolina. U. S. Geol. Survey Geol. Atlas of the U. S., No. 222, 1931, p. 6.

10/ Hess, Frank L., Lithium in North Carolina: Eng. and Min. Jour., vol. 137, July 1936, pp. 339-342.

11/ Dr. J. J. Kennedy, Maywood, N. J., reports these results from many years of experience.

After this lecture was delivered it was found at the Eastern Experiment Station of the Bureau of Mines, that spodumene from Kings Mountain after careful removal of stained particles carried as little as 0.16 percent Fe_2O_3.

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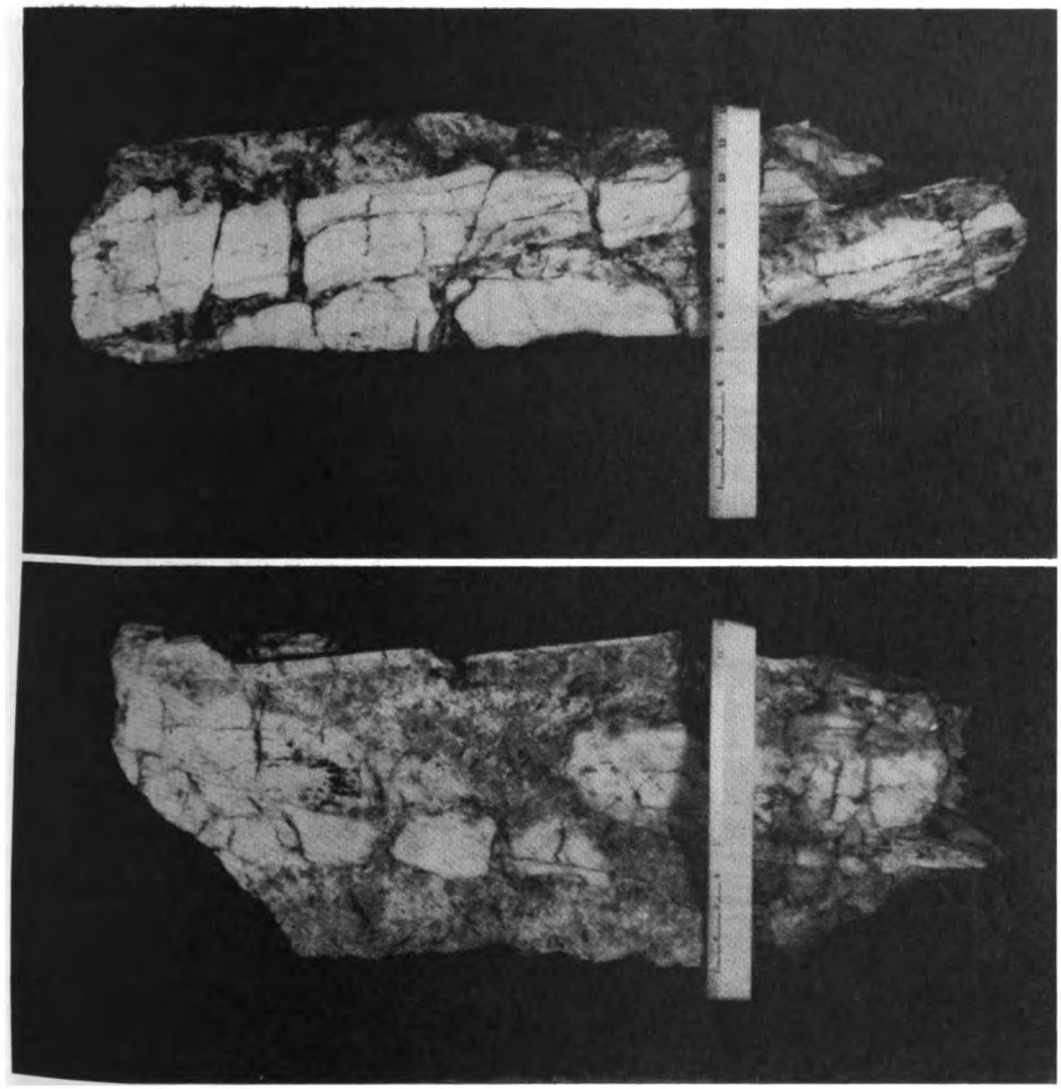

Figure 4.- Spodumene crystals from L. M. Williams' workings 2 1/2 miles southwest of Kings Mountain, N. C.

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at bright-red heat and at tremendous pressure, together with silicic acid, which seems to be very active at such a temperature. There is also more or less fluorine, chlorine, phosphorus, boron, and other active elements, each of which holds all it can carry of various elements both common and unusual. They are like people who, suddenly ejected from their homes, carry their arms full of their belongings as they flee.

The solutions come from every minutest part of the granite and follow cracks toward the surface of the earth through the cooler pegmatites, and there they drop the parts of their loads that they cannot carry at the freezing temperatures, and pick up, in exchange, material they can carry, and hurry on. Occasionally they form pegmatitic veins beyond the pegmatite itself.

Although the load of lithium is probably greater than that carried at Durkheim, it is likely only a few times greater; hence, the flow of waters must have been huge in the aggregate, especially as probably only part of their lithium load was left behind. Undoubtedly, they carried a considerable part several miles farther upward, finally emerging as fumaroles like the steam vents in Yellowstone Park, gradually cooling to hot springs like Durkheim.

It will have been seen from what I have said that, at least in this country, spodumene is at present the most available source of lithium in large quantity, but that amblygonite, being richer, ordinarily will be preferred for the extraction of lithium salts as long as it is available.

In the Etta mine the spodumene crystals are so large that they can be hand-picked readily and thus make an acceptable product that carries 6 to 6.5 percent Li_2O. In North Carolina the pegmatite cannot be hand-picked to carry much more than 3.5 percent Li_2O, which means that it then contains a little more than 50 percent spodumene.

Spodumene has a specific gravity varying from 3.13 to 3.20. The accompanying minerals - quartz, feldspar, and mica - have specific gravities of about 2.65. As spodumene cleaves into flat enlongated particles, the difference is not great enough to allow clean separation of the spodumene by ordinary gravity methods. As none of the minerals are magnetic, magnetic separation doesn't help, nor do electrostatic methods.

Ralston and Fraas, of the Bureau of Mines, ingeniously took advantage of the fact that spodumene swells and breaks to a powder on being heated to 1,100° C. The accompanying minerals powder not at all or only slightly under such heating. The heated material can then be screened through an 80-mesh screen and a fairly clean powdered product can thus be obtained. Care must be used not to overheat the rock, because spodumene melts at about 1,375° C.

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The powder so made contains only 6 percent Li_2O, or a little more, and to obtain a more concentrated product they devised a method by which the powder is mixed with calcium chloride and then heated to 1,100° C., or higher, to drive off lithium chloride, which must be precipitated by some method such as condensing it in water or precipitating it in a Cottrell precipitator.

The Bureau of Mines has published an account of flotation experiments[12] that saved 50 percent of the spodumene, but it seems sure that the results can be greatly improved and that flotation will work as well on spodumene as on other minerals.

And at this point let us turn again to Searles Lake. You will remember that I said that its brine carried 0.032 percent LiCl. For a number of years borax, soda salts, and potash have been extracted from the brines. In boiling the brines trouble has been had with foaming, which was supposed to be due to organic matter. In places, the salt takes a beautiful pink color from some low plant growth, so that organic matter is present. Finally, a chemist was put to work on the foam and found that a lithium salt caused the trouble. In was found also that it could be separated, and now lithium-sodium phosphate is being shipped at the rate of 300 tons per year. The lithia content, according to spectrographic tests made by Morris Slavin, is about 25 percent Li_2O, which means a content of 75 tons of lithia, or nearly 35 tons of lithium.

If Searles Lake can do this, probably the great salt deposits of New Mexico, Spain, Alsace-Lorraine, Stassfurt, and Perm, one or all, may do it, and at a later date the surface salt deposits of Peru, Bolivia, Chile, and Argentina. The playas of Arizona, California, Nevada, and Oregon also loom as possibilities.

EXTRACTION OF LITHIUM SALTS

Lithium salts apparently are extracted from lepidolite and zinnwaldite[13] by mixing the powdered ore with an excess of potassium sulphate and raising the temperature to a moderate red heat, below the melting point of the constituents. Lithium sulphate can then be extracted by solution. The lithium sulphate is changed to carbonate, and from that other salts are made.

It is said that in Germany low-grade lepidolite is being treated with sulphuric acid and the lithium is precipitated as fluoride[14] which

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12/ Davis, C. W., Progress Reports, Metallurgical Division. 16. Ore Testing Studies: Rept. of Investigations 3328, Bureau of Mines, February 1937, pp. 104-108.

13/ Osborg, Hans, Lithium. Theoretical Studies and Practical Applications: 1935, pp. 10-11.

14/ Frydlander, J. H., Le lithium et ses composes. Etat naturel, preparation et usages: La. Rev. prod. chim., an. 33, 1930, p. 99.

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is then made into other salts. Spodumene is treated by roasting with sodium bisulphate followed by lixiviation. I know of no publication dealing with the treatment of amblygonite but presumably it could be treated with sodium bisulphate or with sulphuric acid.

ELECTROLYSIS

The metal was first electrolyzed from the melted lithium chloride. It was soon found that the addition of an equal quantity of potassium chloride lowered the melting point from 610° C. to about 450° C. and this method[15] still seems to be the best. The purity of the metal may reach 99.5 percent.

PRODUCTION

At present the world's known output of lithium minerals comes from the United States, South-West Africa, Sweden, Portugal, Germany, Czechoslovakia, and Australia and amounts to about 4,400 tons of all types, as follows:

Short tons		Li_2O, percent		Li, tons
3,000	lepidolite and zinnwaldite, carrying	3	about	42
1,000	amblygonite, carrying	8	"	38
400	spodumene, carrying	4	"	16
4,400				96

These figures are offered as approximations. They do not contain the output from Searles Lake which has only recently begun.

It's a small business, but that is not necessarily a mark of uselessness: What would you take for your electric lights? Yet, all the electric lamps in the world could be made from a couple of hundred tons of tungsten concentrates. And some small businesses grow.

USES

Well, what is lithium good for? I found 427 American patents concerned with lithium listed by Worden[16] as issued in the 10 years, 1915 to 1924, and I am not sure that I found them all. This does not include foreign patents, and it seems safe to assume that more than 1,000 patents must have been issued; so a number of people have tried to find what it is good for.

Paracelsus is quoted as having said that the object of chemistry is to produce medicine, and, so far as I can learn, the first use of lithium was as medicine. The theory behind its use was that when calculi had formed in body cavities, lithium would replace the calcium in the

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15/ Osborg, Hans. Work cited, p. 10.
16/ Worden, Edward C., Chemical Patent Index, United States, 1915-24: vol. 3, index F-1.

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calculi and, the lithium salts, being soluble, the calculi would disappear. The lithia was usually taken by drinking the waters of springs supposed to carry it in solution. Some springs really contain lithium, but always in association with 20 or more other elements, many of them in very much larger quantity, and nearly all available analyses show many times as much calcium, the mineral one desires to get rid of, as lithium. However, lithium-water drinking became so popular that the lithium-water business became a racket. Finally a law compelled the sellers to really have lithium in the water so advertised and the sale of lithium salts to the water bottlers became large.

The dosage of lithium is said to be 2 to 5 grains of various salts. The Hathorn spring at Saratoga, N. Y., one of the favorite lithia springs and one of the richest as quoted by Clarke[17] carries about 24 parts of lithium per million. Supposing a dose of medicine to contain 1 grain of lithium, then the patient would have to drink 143 pounds, equivalent to more than 17 gallons of water. This would make a pretty good bath, and that is just for one dose. Certainly one should take a dose after each meal!

For years this was the chief use of lithium. However, so many became convinced that the desired results were not obtained that the demand fell, until the Etta mine, the principal producer in this country, was closed for several years.

Meanwhile, other uses were springing up. Edison invented an alkaline storage battery in which lithium hydroxide[18] is used.

In welding aluminum and other metals, lithium chloride and other salts have been used as a flux to dissolve the oxide coating on the aluminum and to prevent oxidation of the molten metal. Lithium carbonate and lithium-strontium nitrate are used in pyrotechnics to give a red color to the flame; but, when an effort was made to color wood fires to add beauty to a fireplace it failed. Perhaps, however, beautifying an open wood fire is painting the lily.

Some lithium has been used in purifying metals, and Meehanite is a very close-grained cast iron that has been treated with an alloy of lithium and calcium. It is reported that the bronzes used in electrifying the Pennsylvania Railroad were treated with the same alloy. Lithium calcium alloys are made in two principal types - one 50 percent Li and 50 percent Ca, and the other 30 percent Li and 70 percent Ca[19].

17/ Clarke, F. W., The Data of Geochemistry: U. S. Geol. Survey Bull. 770, 1924, p. 188.

18/ Chambers, G. K., and Enck, E. G., Lithium Ores and Lithium Salts: Foote-Prints, vol. 7, 1934, p. 1.

19/ Osborg, Hans, Work cited, p. 10.

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It is well-known that if the humidity is low, both higher and lower temperatures can be experienced without discomfort than if the air is humid. Factories may be made very much more comfortable in such a climate as that of Washington, D. C. by merely drying the air. Lithium chloride is one of the most hygroscopic salts known, and by pumping air through a 60-percent aqueous solution of lithium chloride most of the moisture can be removed.

The chloride is then regenerated by merely heating it to drive off the water. Mixtures of lithium chloride and lithium bromide and of lithium chloride and calcium chloride for similar use have been patented. A considerable number of plants for this process have been installed recently.

Here in the Bureau of Mines Experimental Station on one oppressive day in August when the humidity was so high that I could not use an electroscope, Foster Fraas was good enough to set such a machine to work to dry out his room for me. Of course, the room had to be closed and I felt that I had been sentenced to part suffocation, but after the machine had worked a while I stopped perspiring and made the tests in comfort.

Germany, as we know, has made desperate efforts to free herself from the necessity of buying foreign goods. Heretofore, tin has been considered a requisite for making bearing metals, but the Germans have devised an alloy known as Bahn or BN metal, which is composed of lead with the addition of small quantities of an alkali earth metal and one or more alkali metals. An analysis is given as: Lithium 0.04, calcium 0.73, sodium 0.66, potassium 0.03, aluminum less than 0.2, lead balance. It is claimed to be as strong as tin-lead bearing metals when cold and stronger when warm, and saves the Germans from buying a large quantity of tin. The fly in the ointment seems to be that the bearings must be put in by an expert.

From time to time considerable lepidolite has been used in glass making, especially in glasses in which a low coefficient of expansion is desired, and a recent patent covers the use of lithium in astronomical mirrors.

Three hundred and fifty tons of lepidolite were shipped recently from one property in the Black Hills to a glass company.

Besides reducing the coefficient of expansion under certain conditions, lithium would make a much more liquid glass melt, a useful quality in glass to be molded.

But what seems to be the hopeful use for lithium is in pottery. Shrinkage can be overcome by proper mixing of spodumene in whiteware bodies, and at the same time it will reduce the firing temperature considerably - a matter not only of cost of fuel or current, but, in electric firing, an important item in the cost of heating elements.

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Robert J. Gould, formerly in charge of the T.V.A. ceramic laboratory at Norris, Tenn., wrote to Oliver C. Ralston concerning tableware and other pottery: "Seven percent of spodumene had approximately the same fluxing property in a ceramic body as 20 percent regular feldspar." A lower temperature would be required for firing.

Most tableware is glazed with a mixture of lead oxide, silica, feldspar, and other ingredients, according to the potter's fancy. Some contains so much lead that the potters say "It will melt in a cup of coffee." It is dangerous to the health of employees, costly, and does not make a hard glaze.

Preston,20/ an English ceramist, says that 0.5 percent Li_2O added to chinaware glazes "gives a decided improvement in the fluidity and surface tension of the glaze, producing greater uniformity, eliminating pinholes to a large degree, and giving an increased gloss." If the spodumene contains too much iron, salts can be made and used.

In spite of a thousand patents, more or less, covering lithium uses, extraction, etc., the best prospect for our large deposits seems to be in pottery, and I hope that in time the Bureau of Mines experimental laboratory at Norris, Tenn., will be able to make the advantages of such a use so plain that the use must come, provided that the apparent advantages are real.

20/ Preston, E., Lithium in Glass and Ceramics: Foote-Prints, vol. 11, no. 1, July 1938, pp. 1-15.

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